The correlation of enhancement and fading on terrestrial point to point links

M.J Willis, K.H Craig

Radio Communications Research Unit, Rutherford Appleton Laboratory, UK

Keywords: Trans-horizon propagation, measurement, joint statistics

Abstract

This paper summarises the results of a long term propagation measurement campaign recently completed in the United Kingdom with respect to the correlation between the fading of wanted signals and the enhancement of unwanted interference. The correlation has been modelled and the paper demonstrates the importance and application of correlation modelling in link planning.

1 Introduction

The radio spectrum is a limited resource and it is necessary for fixed link radio systems to share spectrum. When a new link is required, a channel and a transmission power must be allocated that allows the link to meet a desired quality of service without causing or suffering excess interference. Channel assignment algorithms aim to optimally pack links while managing interference at an acceptable level. To do this, it is necessary to calculate the aggregated interference at each receiver from all other links. An important input to this calculation is a method for the prediction of the instantaneous signal levels arising from multiple sources. Assumptions about the degree of correlation of interfering signals have a significant effect on the spectrum utilisation factor.

Assignments made within the UK are based on statistical predictions of signal strengths and using the relevant ITU-R recommendations (ITU-R P.530 [1] for the wanted signal and ITU-R P.452 [2] for unwanted interference paths). Paths that are not line of sight frequently show considerable variability in signal strength over time and while the ITU-R recommendations provide reliable predictions of the probability density function (PDF) of signal strength against percentage of time on a single path, they currently give no advice on the correlation of signal strength between different paths and so can not be used to predict aggregate interference. The long term measurement campaign (LTMC) was set up in order to assess what the true correlation is between fading and enhancements on typical paths used in the fixed link service [3].

The experiment consisted of an instrumented hub station where the signal levels from 7 outstations converged. This is shown diagrammatically in Figure 1. The outstations were arranged to accurately simulate real interference cases with typical near limit margins, i.e. links that would only just pass current allocation criteria. The choice of test frequencies of 1.4 GHz, 7.5 GHz and 18.6 GHz and the length of the reference link at around 60-80 km was made based on the current loading of the fixed service bands. The results of this experiment have been reported in [4].

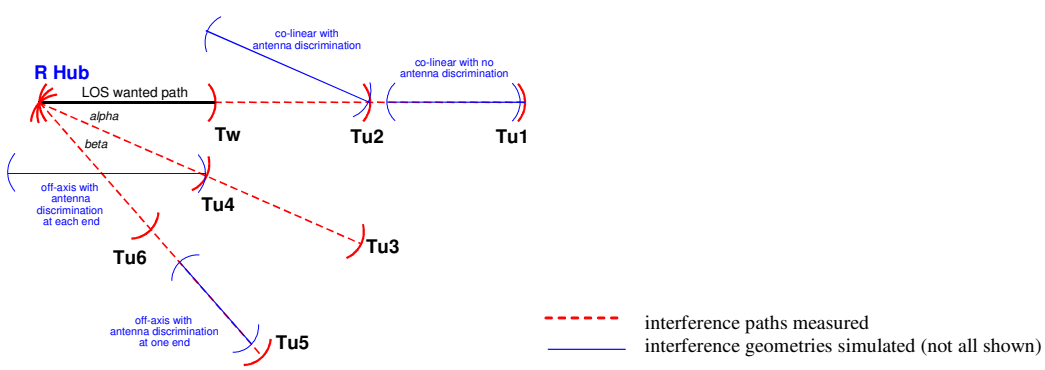


Figure 1 - Cluster configuration

2 Joint statistics

Figure 2 shows a sample combined signal PDFs. The joint PDF is generated from time series data of two channels with one channel controlling the X axis and the other the Y axis. The Z axis in these plots is the relative frequency of the associated combination of X and Y signal amplitudes. The Z axis is represented by a logarithmic decade colour scale of probability as fixed link interference planning requires knowledge of rare combinations.

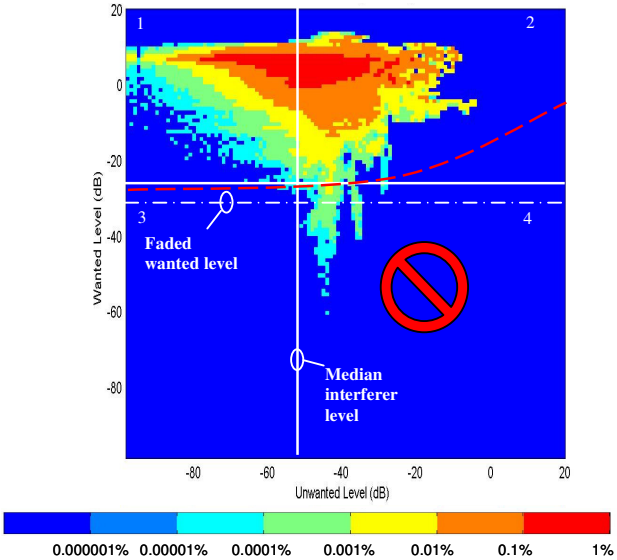
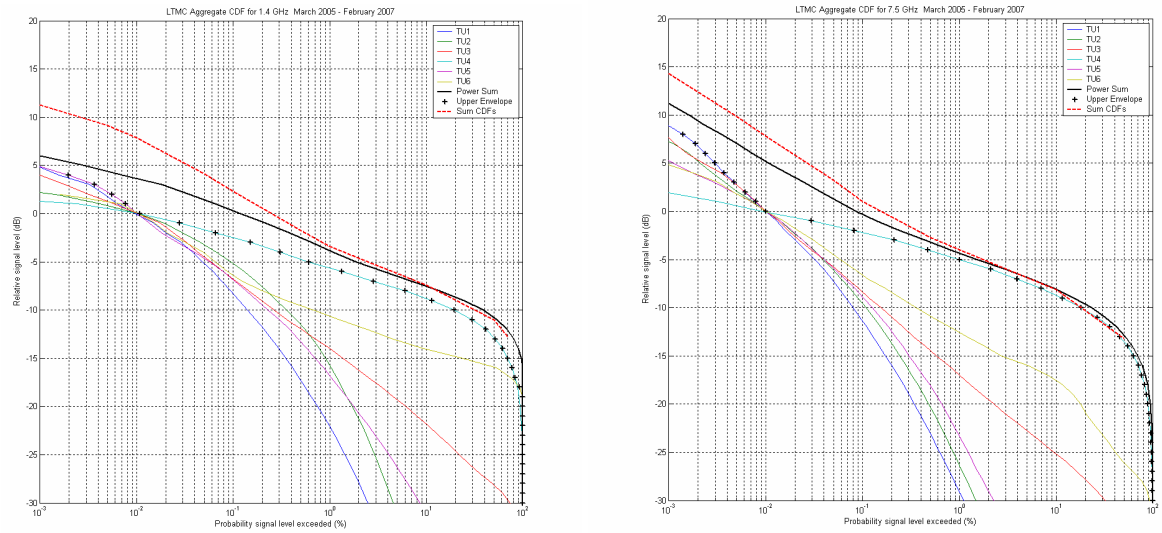


Figure 2 - Joint PDF

Outages occur when the carrier to noise plus interference ratio falls below the required threshold for the service, typically around 10-20 dB. This situation is represented by the dashed red line in Figure 2. The outage time is the integral of Figure 2 below this line. Traditional link assignment methods which do not have the luxury of joint statistical data are represented by two lines in Figure 2, the "Faded Wanted Level" and the "Median Interferer level". The faded wanted level is the minimum signal to noise ratio for the link to operate. A small margin is added to the minimum faded wanted level to account for interference; this is represented by the horizontal solid white line. The median interferer level is constrained by assignment to not exceed a protection margin, typically 30dB below the faded wanted level. It is assumed interference is not enhanced while the wanted signal fades. If the joint signal levels fall within regions 1 or 2 of Figure 2 it is assumed there will not be an outage. There is no information used regarding the correlation or otherwise of wanted signal fades and the aggregate interference. Independence between fading and enhancement is assumed and multiple interferers are covered by a small additional margin. This can lead to inefficiency. If all interfering signals fade at the same time as the wanted signals then the interference margin is unnecessary. Conversely, if interference is enhanced while the wanted signal fades the margin may be too small. If all interfering signals are enhanced at the same time the aggregate interference level may exceed the multiple interference margin.

In the case of the LTMC we have real measured data and it is interesting to see what the aggregated interference statistics of interference are with a network just meeting frequency allocation criteria. Figure 3(a) shows the cumulative distribution function (CDF) of the received power for the six 1.4GHz LTMC trans-horizon signals with all channels normalized to the same power level at 0.01% time. It also shows the power sum of all channels sampled once per second over the two years of the database. Figure 3(b) shows the same result for 7.5GHz. The power sum line is the interference that the wanted link would suffer in practice. This line lies close to the dominant interferer (TU4) for high time percentages and deviates significantly at low time percentages. Note that this line must always lie above the upper envelope of the individual CDFs, the CDF envelope can therefore be used as a lower bound. The traditional assignment methods are effectively based on constraining this lower bound at 50% time and 0.01% time. Note that the power sum at 0.01% is not six times (7.8dB) the power of each interferer, this is because the interferers are not fully correlated and assuming full correlation in planning would be overly pessimistic. The traditional method allocates each interferer in

sequence as the links are deployed and allows a small margin of 1-3 dB to allow for the aggregation of multiple interferers; A 3 dB margin in this case would not be enough.



(a) (b)

Figure 3 – Aggregate signal levels for the trans-horizon LTMC paths

The "Sum of CDFs" curve represents the aggregate power that would be received if all the interfering signals were "fully correlated" that is, the received powers from the individual paths are simply added at every time percentage. This can be considered as an upper bound to the interference at the higher time percentages, although the power sum can exceed the "Sum of CDFs" curve at the higher time percentages as is shown in Figure 3.

The actual margin required lies between the envelope of the individual CDFs and the power sum of the CDFs. To determine where this is, it is necessary to know the joint statistics of the links. Prediction models exist within the ITU-R [1][2] which are able to reproduce the CDF, as shown in Figure 4. However they say nothing about the joint probability.

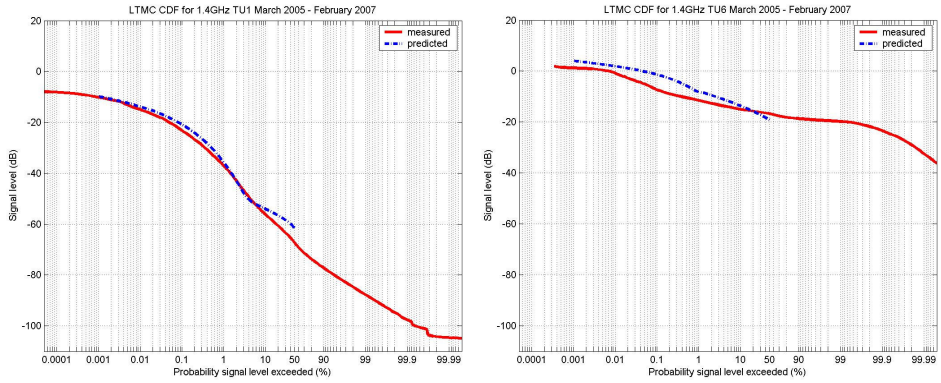


Figure 4 – Examples of predictions based on ITU-R P.452

3 Modelling

The multi-dimensional joint statistics have been modeled for links using the ITU-R P.452 and ITU-R P.530 models together with a correlation function based on Copula techniques with the driving parameter based on link geometry [5]. This work is ongoing and has been submitted to the ITU-R. Monte Carlo techniques are used with the multivariate

random number generators based on Copula functions. A tentative Copula based model output is given in Figure 5. The Envelope and sum of CDF curves are as for Figure 3. The "fixed rho" line is a statistical simulation assuming a fixed correlation factor. The Copula model is based on the method described in [6] using the measured CDFs as inputs.

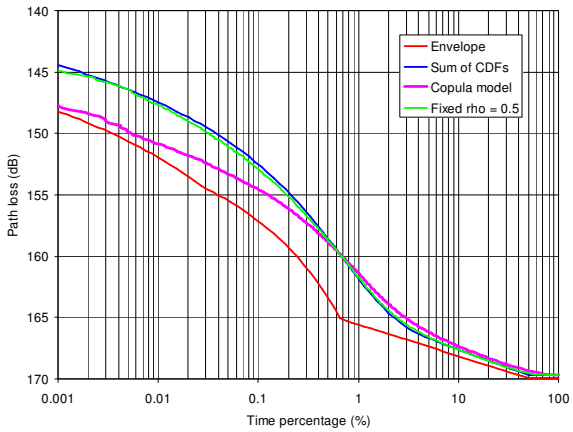


Figure 5 – Results from interference aggregation model

While this model still needs development and testing it gives encouragingly similar results to the measurement results shown in Figure 3.

4 Conclusions and further work

A campaign to measure the joint statistics on interference in the fixed links service has been concluded. The results from this campaign have demonstrated that current link assignment methods while not seriously in error have room for improvement. A tentative model for evaluating aggregate interference based on existing models and link geometry has been developed. Further work is required to develop this model. As there are very few joint signal level measurements available, to extend these results to other climates and link geometries will require further measurement campaigns similar to the LTMC.

5 Acknowledgements

This work was sponsored by Ofcom under the spectrum efficiency scheme. The measurement campaign was undertaken by the Rutherford Appleton Laboratory greatly assisted by BT Exact.

6 References

[1] ITU-R Recommendation P.530-11, "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems", Available from ITU http://www.itu.int

[2] ITU-R Recommendation P.452-12, "Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz", Available from ITU http://www.itu.int

[3] Terrestrial fixed link assignment criteria for Fixed Point-to-Point Radio Services with Digital Modulation, Documents OfW46, OfW47 & OfW50, available from Ofcom http://www/ofcom.org.uk

[4] Results from a long term propagation measurement campaign, Mike Willis, Ken Craig, ISART 2007, Boulder Colorado

[5] A Model for the Correlation of Fading and Enhancement on Radio Links, K.H. Craig, ISART 2007, Boulder Colorado

[6] "Sharing the spectrum efficiently - Modelling interference from multiple sources", Ofcom SES 2005-9 Final Report. http://www.ofcom.org.uk/research/technology/research/prop/multinter/